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PREFACE

Earlier reports in the Summary of Underwater Acoustic Data series have attempted to summarize existing knowledge about the parameters which appear in the sonar equations. These relationships which find application in many problems involving underwater sound are stated for reference in Part I of the series. As outlined in Part I, the objective of the summary has been to provide a condensation of some of the basic data in underwater sound for use by practical sonar engineers.

During the preparation of these reports various aspects of the state of knowledge of the parameters have become apparent. While some features of the sonar parameters are known with comparative certainty, there is virtually no information on others. In this report,* issued as Part VIII of the series, an attempt is made to summarize in broad terms the state of knowledge of the individual parameters and to point out areas where this is deficient or abundant, particularly in so far as the practical sonar engineer is concerned.

The complete list of reports in the series follows:

Part I	– Introduction (July 1953)
Part II	– Target Strength (Dec. 1953)
Part III	– Recognition Differential (Dec. 1953)
Part IV	– Reverberation (Feb. 1954)
Part V	– Background Noise (July 1954)
Part VI	– Source Level (Radiated Noise) (May 1955)
Part VII	– Transmission Loss (in preparation)
Part VIII	– The Sonar Parameters – The State of Our Present Knowledge (May 1956)

*The report first appeared in the Journal of Underwater Acoustics, Vol. 6, No. 1, Jan. 1956, and is largely based on a paper presented at the 11th U. S. Navy Underwater Acoustics Symposium in June 1955. It is reprinted here because of its direct relation to the earlier reports in the series.

CONTENTS

THE SONAR PARAMETERS - THE STATE OF OUR PRESENT KNOWLEDGE

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INTRODUCTION

We are all aware that underwater sound has had, by this time, a rather long history which dates back to the first World War, when a simple listening device was used for finding U-boats. In the succeeding years, the handful of men that were engaged in the subject sought and found more and more efficient transducers, and developed a practical echo-ranging system. By the year 1935, attention could begin to be given to some of the underlying phenomena of underwater sound. Perhaps the most perplexing feature at that time (and one which still remains an important problem) was the wide variation in detection ranges that were observed from day to day, and place to place, with the then newly-developed echo-ranging sonar. In the year 1935 there appeared what may be the first basic report - a report on attenuation of sound in the sea by E. B. Stephenson of NRL.[1] This may be taken to mark the beginning of basic research; it may be said that the present year marks the twentieth anniversary of fundamental underwater acoustics research. The following years saw a period of continuing progress toward an understanding of basic phenomena - a period of intense research activity during the war, and a post-war period marked by a great expansion of the fields of useful Naval applications.

During this long period of historical development a surprisingly voluminous literature has come into being. This literature now totals some 10,000 to 12,000 reports and documents. Of this number perhaps a thousand may be said to deal with measurements of the basic sonar quantities and their interpretation in a rational manner.

This abundant and growing literature presents a major problem to the sonar engineer interested in equipment design and performance prediction. If he desires a value for, let us say, the radiated-noise level of a submarine under certain conditions he is forced into a long and tedious search of scattered documents, and usually ends up by resorting to one or two selected instances as the basis for an estimate.

In order to alleviate this situation that has been a hindrance to rational system design, we have been engaged in a summary of acoustic data to provide the sonar scientist with the information he needs for equipment design and performance prediction, together with some

understanding of why the values are the way they are.[2] Such information is most systematically given in terms of the so-called sonar parameters - those somewhat arbitrary quantities that enter into the basic sonar equations and which encompass much of the whole subject of basic underwater sound research. They occur in nearly every practical application and form a common ground for workers in diverse fields. The parameters are listed in Table 1 together with an indication of whether each pertains to one-way listening or two-way echo ranging. Once these parameters are known with sufficient accuracy - together with a few less uncertain quantities like directivity index and sound velocity - a detection range may be predicted exactly, because the sonar equations are logically complete when the parameters are suitably defined.

TABLE 1
The Sonar Parameters

Parameter	For Passive Systems	For Active Systems
Target Strength		√
Recognition Differential	√	√
Reverberation		√
Background Noise		
Ambient Noise	√	√
Self Noise	√	√
Source level		
of Projectors		√
of Targets (Radiated Noise)	√	
Transmission Loss		
One way	√	
Two way		√

During this survey, certain aspects of the state of knowledge about these parameters have become evident. Some features appear to be known with definiteness and comparative certainty, other aspects are not known well enough to satisfy even the crudest sort of requirement of the design engineer. These features may best be pointed out by considering each of the parameters in turn, and painting with a broad brush some of the aspects wherein our knowledge is deficient or abundant.

TARGET STRENGTH

Let us consider first the parameter - target strength - which is a measure of the scattering or reflecting ability of targets (Figure 1). In most of the field measurements of this

quantity a single frequency and pinglength have been used. Usually target aspect has been the variable, with the result that our knowledge of the aspect dependence of target strength at high frequencies is reasonably good. On the other hand, the behavior of this parameter with such things as frequency and pinglength is much less well known. For example, it is surprising to find that no data appears to have been obtained with pinglength as a systematic variable.

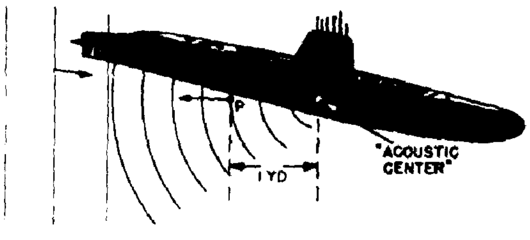

Figure 1 - Target strength = reflected level at P - incident level

Target strength is a parameter the measurement of which is intimately tied up with transmission loss. This needs to be known in order to reduce a measured echo level back to what it would be at one yard. As a result, the determination of target strength is subject to the vagaries of echo propagation at sea. The reported values for submarines are surprisingly divergent. Indeed, the beam-aspect target strength of a submarine has been reported to be as low as 12 db and as high as 37 db. Although some of this spread must be due to differences in pinglength and frequency, transmission loss is likely to have been the principal offender. Any new measurements must be made under conditions such that this quantity is accurately known.

The other target that has received considerable attention is the mine. Recent data on mine target strengths over a range of pinglengths and frequencies is generally consistent, and is probably adequate for needs of current mine-hunting sonars. Mine data at low frequencies, short pinglengths, and for mines in and on the bottom will be needed for future use.

There are some sonar targets which are not at all well known target strength-wise. One of them is torpedoes. Other poorly known targets are the various types of surface ships on which virtually no measurements have been made since the war. The various so-called false targets that are apt to be mistaken for submarines, such as whales, kelp beds, and so forth are also unknown from a target strength standpoint, even though this factor might be a valuable aid in target classification.

RECOGNITION DIFFERENTIAL

The second parameter is recognition differential, shown in Figure 2, which is closely allied with directivity index in expressing the discrimination of the system against its background. Directivity index is a measure of the discrimination provided by the transducer, whereas recognition differential pertains to the rest of the system, including the observer. It is the signal-to-noise ratio required for some function — such as detection, or classification, or torpedo homing. Its definition normally is very loose, without any statements as to the percentage of false indication or the amount of time permitted for observation. If there are no limits on the number of false calls or on observation time, then any signal, however small, may be picked out of its background. Once the time and false-call

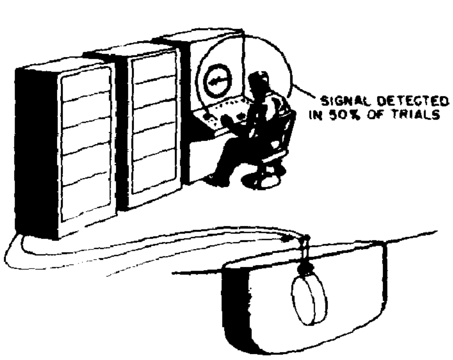

Figure 2 - Recognition differential = S/N ratio at transducer terminals

percentage are specified, there is a limit to the recognition differential that can be achieved by any detection scheme using a single statistical property of signal and background.[3]

Most measurements have been made for listening. Our knowledge of aural differentials is quite complete for ideal signals in Gaussian noise. Strange to say, there is little aural data on the detection of real echoes in actual sea noise. For reverberation backgrounds there is also little post-war data on aural differentials, especially for the long pulses now of interest in long-range sonar.

For the visual detection of signals, as on a PPI screen, there is a slight amount of data available on the recognition differential for noise backgrounds, but virtually nothing exists for reverberation.

One especially important gap that should be mentioned is our lack of knowledge about what might be called observer loss. This is the loss in detection ability suffered by an observer who is tired, disgruntled, or otherwise different from the ideal observers used in laboratory trials. Some observer measurements are needed under actual sea conditions. An analysis of what leads to poor detection performance is an important problem for the future.

REVERBERATION

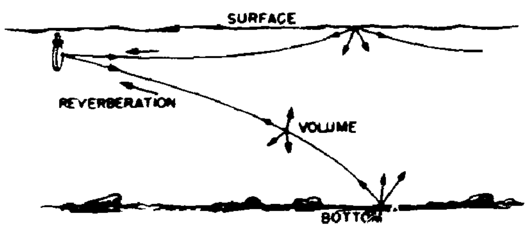

Figure 3 - Reverberation level can be computed from a coefficient, 10 log m, where m is the backscattering cross section of unit area or volume, as appropriate

The third parameter is reverberation (Figure 3), which is a form of background that can be specified by a parameter called the backscattering coefficient for the various scatterers existing in the sea and its boundaries. Reverberation is perhaps the most neglected single basic subject; it has received little study in the post-war years despite its importance to active homing torpedoes, to acoustic mine-hunting, and to high-power long-range echo ranging.

The principal post-war activity on this subject, motivated by the needs of acoustic mine-hunting, has concerned measurements of the backscattering from natural bottoms. The bottom scattering coefficients obtained by different laboratories have proved remarkably consistent. They support the view that the roughness of the bottom is normally the dominant source of backscattering. Unfortunately, there is no data below about 2° in grazing angle, where the initial detection of mines often occurs.

In contrast to bottom reverberation, surface reverberation has received almost no attention in this country since the wartime measurements which showed a wind-speed dependence to the reverberation at short ranges. We are as uncertain as we were during the war, as to whether surface reverberation is due to surface roughness or to a layer of bubbles, or both.

When we turn to the third major source of reverberation - volume scattering - we find that a number of measurements have been made against depth in a few areas. But they are not extensive enough to permit any sort of prediction of volume reverberation level, especially at the moderate and long ranges of current interest in active sonar. In fact, we hardly know how to go about a long range prediction when more than one source of reverberation is present.

One relatively simple subject that has suffered from neglect is the frequency spread of reverberation. This would not only give clues as to the nature and motion of the scatterers, but would provide valuable data as well for the design of reverberation-suppression filters.

AMBIENT NOISE

Another parameter concerns the noise background, which may be either ambient noise or self-noise depending upon whether the natural environment or some man-made source, is the principal source of noise (Figure 4).

Turning first to ambient noise, we find a somewhat unique parameter in that its mean level in deep water is reasonably well established over most of the spectrum. In fact, at high frequencies, the so-called Knudsen curves that were first drawn during the war still remain a standard of comparison for subsequent measurements.[4] Indeed, they may even provide a sort of rough calibration of hydrophones in deep water if the wind force is known. On the other hand, our knowledge of average ambient noise levels at frequencies below 1 kc is less precise, but even here it has improved considerably in the past few years.

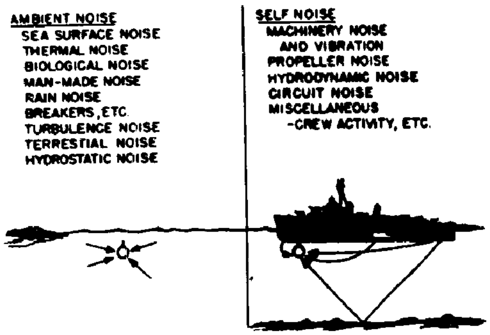

Figure 4 - Types of background noise

In spite of this knowledge of ambient-noise mean level, we are almost completely in the dark about the relative importance of the various causes of ambient noise in different parts of the spectrum. The origin of sea-surface noise is still a mystery. We know little about other properties of ambient noise, such as its amplitude statistics, its time variability, and depth dependence.

In contrast to deep water, we know little about the expectable ambient-noise level in shallow water or in bays and harbors. Many measurements of a descriptive and survey type on the noise level in various harbors were made during the war, bit in spite of this wealth of data, we still cannot predict in advance the ambient level to be expected at a particular shallow-water location.

SELF-NOISE

Self-noise is a subject which has received sporadic attention over the years, ever since it was found that a streamlined dome was needed to make echo-ranging possible for a ship underway.[5] Many measurements and observations of self-noise have since been made. Most of these came as a by-product of equipment field trials; and with one exception,[6] there has not been any broad program in this country on the self-noise of ships to uncover the facts about its origin and about the paths between source and hydrophone. Our knowledge has been built up piecemeal fashion, with only rare instances where some specifically designed experiments were carried out. This is an inherently complex subject, with numerous sources of noise that change their importance with different conditions. It is plagued by the many difficulties of

doing experimental work on naval vessels. By contrast, the self-noise of torpedoes has received continued study over the years, and torpedoes are now perhaps the best known of all naval vehicles from a self-noise standpoint.

The problem of prediction for a contemplated or partly designed system is the important one for the design engineer. At present, we can do little in the way of prediction unless the transducer, and its location and mounting, are reasonably conventional. For completely unorthodox systems, a self-noise prediction is virtually impossible until we know the relative importance of the various sources and paths of self-noise. This knowledge is vitally important for noise reduction also, for it must be realized that it is useless to attempt to reduce unimportant noise sources and unimportant noise paths.

Recent work has re-emphasized that a clean undamaged dome is a requirement for low self-noise.[7] On the other hand, it is becoming clear that something else is required at high speeds. Recent work has revealed a new noise source — the so-called "rush noise" — that is probably the principal noise source on ships traveling at high speeds in deep water.[8] In shallow water it is masked by propeller noise coming by way of the bottom. This rush noise probably has some sort of hydrodynamic origin; by air bubbles or turbulences striking the dome, by the flow of water about small roughnesses in the dome surface, or by some unknown cause or combination of causes. It would seem that for high speeds the shape, material, and location of sonar domes once more become important.

SOURCE LEVEL

The next parameter is source level, which refers to the sound output of sonar projectors or of ships and torpedoes and is a measure of the noise they radiate (Figure 5).

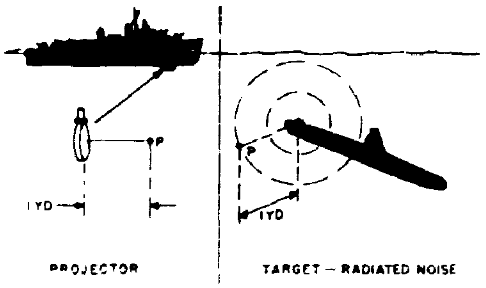

Figure 5 - Source level (radiated noise) = level at P

There is one respect in which the noise-level data of ships is different from other sonar parameters. It is that measurements are surprisingly abundant and the literature on the subject is quite extensive. In fact, radiated-noise level data has been obtained on at least 17 sound ranges in this country, and in Great Britain, during and since the war. Unfortunately however, most of this abundant literature is essentially useless to the design engineer who wishes a mean level, and an idea of the expectable spread, for a particular type of ship under some given conditions. In general, he must resort to individual measurements or to some haphazard partial summaries for the db values he needs. Except for noise reduction purposes, what may be most needed at the present time is not more data but some good summaries of the data already in the literature. An allied feature of the literature that should be mentioned is the tendency of reports to contain no references to prior measurements on the same type of vessel by other laboratories, or to make any comparison between the new vessel and other vessels of the same type.

In spite of the literature available, some broad gaps in our knowledge appear to exist. One very important one is the lack of radiated-noise data on submarines operating at speeds above about 12 knots or at depths below two hundred feet. For these conditions there are only

a few isolated measurements in hand, and more measurements on high-speed deep-running submarines are needed.

TRANSMISSION LOSS

The final parameter that we have to deal with is transmission loss, which specifies the decrease in level suffered by a signal as it travels outward from the source (Figure 6). It is the parameter concerned with the propagation of sound in the sea and, as such, has received almost continuous attention since the beginning of underwater sound research. It is a parameter which affects the practical measurement at sea of every other parameter with the exception of recognition differential. Its removal from field data is a difficult and often vexatious affair. Any uncertainty in transmission loss turns into an equal uncertainty in the values of all but one of the other parameters.

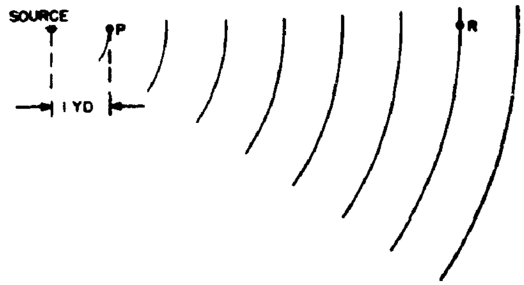

Figure 6 - Transmission loss at R = level at P - level at R

A great many transmission runs have been made in the past, but the confidence with which we can predict the loss depends greatly upon frequency and distance. As a result of the extensive work done during the war and under the AMOS program,[9] our ability to predict an "average" transmission loss in deep water appears to be fairly good at moderate ranges (to 5000 yd.) and at moderate kilocycle frequencies (10 to 30 kc). But as we go to lower frequencies and to longer ranges, the confidence with which we can predict transmission loss gets less and less, even though quite recently there has been a great improvement in our knowledge in this area. Although in deep water we may arrive at some sort of semiquantitative answer by drawing a ray diagram, in shallow water we have not yet learned how to make a reasonably good estimate of transmission loss either for the conditions of interest in listening or for acoustic minesweeping. Again it would seem that the uncertainty increases with decreasing frequency and increasing range. While we may know, or think we know, the general principles of propagation under these various conditions we have not yet been able to translate them into the numerical quantitative terms useful to the sonar engineer.

All this applies to the mean transmission loss averaged over an interval of time or distance. We know almost nothing of a quantitative nature about instantaneous transmission loss that may exist at a particular time or place. Ping-to-ping fluctuations, and the fading of a steady source, are examples of this variability that should be subjects for much future study.

CONCLUSIONS

If we take the broad view of all the sonar parameters, we must conclude that in spite of the gaps that have been mentioned, most of the principal phenomena and effects in underwater sound are reasonably well understood. Although major mysteries of a physical nature still exist, it must be said that they are few in number. Underwater sound has grown beyond its infancy to the point where we possess some knowledge and some conceptual understanding of most of its major phenomena. One would like to think that it has achieved some degree of scientific maturity, and that the exploratory phase of its development is at an end. We can

make guesses that are seldom totally in the dark, and we know, or we can predict in broad terms, the variation of the parameters with some, though not all, of the independent variables.

But this type of basic knowledge is of little value to the practical sonar scientist and engineer. He needs some numbers, some reasonably accurate quantitative predictions, in order to evaluate a proposed system or to understand the behavior in the field of a sonar set already built. He must have a reasonably good value for transmission loss, rather than a statement that ray theory or normal mode theory applies. He wants a value for the scattering coefficient for a particular type of bottom, and cannot be satisfied with the knowledge that the scattering is caused by the bottom roughness. It is in this respect that our knowledge about the parameters is most deficient. It is not often that we can assign a decibel value to a parameter under a given set of conditions with enough accuracy for the design engineer.

At first thought, this is somewhat hard to understand in view of the amount of work that has been done, the amount of money that has been spent, and the amount of literature that has appeared. One reason must be that nothing ever appears to repeat itself in underwater sound. Furthermore, much of our knowledge seems to have been built up by accretion of isolated measurements to fill immediate needs. Moreover, the literature on the parameters is disjointed, and rarely does one find evidence of any real effort on the part of investigators to search the classified literature on their particular problem. As a result, phenomena that were once known have been rediscovered. Often no comparison is possible between new data and similar older data obtained at another laboratory. The end product is one more report in an ever-growing literature.

Perhaps the state of knowledge about the parameters can be summarized in this way. With the exploratory phase over, and with a knowledge of mean values and the underlying physical phenomena, some sort of turning point appears to have been reached. The most urgent need now is for more accurate numerical values useful to the design engineer and the performance analyst. In order to meet this need, future measurements of the parameters must concentrate not only on mean or average values, but on the variations from the mean with a view to improving our ability to make better statistical predictions for a given set of conditions. By a study of variations, and by attention to effects that were once neglected, we may be able one day to use the sonar equations with a high degree of confidence.

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To: Commanding Officer, Naval Research Laboratory (1221.1)

Subj: DECLASSIFICATION OF DOCUMENTS

Ref: (a) NRL ltr 5510 Ser 1221.1/S0048 of 25 Feb 97
(b) NRL memo Ser 7103/713 of 29 Jan 97
(c) ONR Report "A Summary of Underwater Radiated Noise Data, March 1966"

Encl: (1) ONR Report "A Summary of Underwater Acoustic Data, Part I" ~~AD-030 750~~
(2) ONR Report "A Summary of Underwater Acoustic Data, Part II" AD-039 542
(3) ONR Report "A Summary of Underwater Acoustic Data, Part III" AD-039 543
(4) ONR Report "A Summary of Underwater Acoustic Data, Part IV" AD-039 544
(5) ONR Report "A Summary of Underwater Acoustic Data, Part V" AD-105 841
(6) ONR Report "A Summary of Underwater Acoustic Data, Part VII" AD-115 204
(7) ONR Report "A Summary of Underwater Acoustic Data, Part VIII" AD-105 842

1. In response to reference (a), the following information is provided:

Enclosure (1) was downgraded to UNCLASSIFIED by CNR, 7/29/74;
Enclosure (2) was downgraded to UNCLASSIFIED by NRL, 12/3/90;
Enclosure (3) was downgraded to UNCLASSIFIED by CNR, 7/29/74;
Enclosure (4) was downgraded to UNCLASSIFIED by CNR, 7/29/74;
Enclosure (5) was downgraded to UNCLASSIFIED by NRL, 12/3/90;
Enclosure (6) was downgraded to UNCLASSIFIED by CNR, 7/29/74; and
Enclosure (7) was downgraded to UNCLASSIFIED by CNR, 7/29/74.

Enclosures (1) through (7) have been appropriately stamped with declassification information and, based on the recommendation contained in reference (b), Distribution Statement A has been assigned.

2. To my knowledge, reference (c) AD-396 737 has not been previously ~~reviewed~~ reviewed for declassification. Based on our ~~discussions~~ in April 1997, ~~I am~~ still ~~holding~~ it for Dr. ~~Hurdle~~'s comments.

3. Questions may be directed to the undersigned on (703) 696-4619.

Completed
18 Apr 2000
B.W.

Peggy Lambert
PEGGY LAMBERT
By direction